HEALTH ASSESSMENT OF THE LOST FOREST RESEARCH NATURAL AREA

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INTRODUCTION AND BACKGROUND

The Lost Forest, managed by the Lakeview District of the Bureau of Land Management, is located on the eastern rim of the Fossil Lake basin, about 20 miles northeast of Christmas Valley and 30 miles due east of the town of Fort Rock. The Forest extends 5.5 miles from the dry lake bed of the ancestral Fossil Lake eastward beyond Pine Ridge and covers approximately 9,000 acres (Berry 1963). The current forest is a relict of a once-extensive pine forest that occupied the hilltops above a series of pluvial lakes. These lakes dried up completely during a hot and dry period 6,000 years ago and most of the pine forests were replaced by sagebrush and other desert vegetation (BLM 1980). The Lost Forest persisted through the dramatic climate change and now lies about 25 miles east of the nearest pine forest.

Annual precipitation for the Lost Forest ranges from 8-11 inches. Berry (1963) reported the mean annual precipitation from 1900 to 1960 as 8.74", a number that was projected from direct observation at the Cliff weather station. Within that period the drought of the 1920-1936 was considered the worst since 1455 year as indicated in tree ring records (Antev 1935). Berry (1963) also reported mean annual precipitation of 10.66 from 1941 to 1960. The Oregon Climate Service PRISM data-set puts the Lost Forest in the 9" mean annual precipitation class for the 1960-1990 period. Precipitation during these time periods is much less than the 14" typically considered necessary for ponderosa pine establishment and survival (Emmingham and others 2005). The species is able to persist because of the sandy topsoil that is prevalent throughout the area (Berry 1963). This sand is permeable and absorbs a high percentage of the precipitation with minimal runoff. The pumice sands, from Mount Mazama and Newberry Crater deposits (Moir et al. 1978), are highly porous and hold water with little loss to evaporation. The water is readily made available to roots for plant growth. Other significant edaphic features include the hardpan layer (caliche) that underlies all Lost Forest soils and holds water from 16 to 30" below the surface, where it remains available to the roots of both pine and juniper.

Much of the sand in the area is very unstable and occurs in a complex system of dunes. Although most of the dune movement has occurred west and south of the Lost Forest, there has been a significant shifting of sand from the old lakebed of Fossil Lake through portions of the pine and juniper stands. Some trees have been killed and others continue to be partially covered by sand, only to be uncovered later as the sand continues to move through the area. Berry (1963) concluded that while the shifting sand dunes have killed some trees, they do not threaten the entire Forest.

At least six distinct plant communities are recognized in the Lost Forest. The ponderosa pine/big sagebrush (*Pinus ponderosa/Artemisia tridentata*) community occupies nearly 800 acres in the heart of the forest. The ponderosa pine/bitterbrush community (*P. ponderosa/Purshia tridentata*) is found on 600 acres in the eastern portion of the Forest. The largest plant

community, western juniper-ponderosa pine/big sagebrush (*Juniperus occidentalis-P. ponderosa/A. tridentata*), occupies 4500 acres, predominantly in the western and central portions of the Forest. The eastern edge has nearly 600 acres of western juniper/Idaho fescue (*J. occidentalis/Festuca idahoensis*) in a relatively stable community. The remainder of the area is occupied by two sage communities: big sagebrush in the non-alkaline soils, and low sagebrush (*A. arnuscula*) in rocky, thin soiled areas (Moir et al. 1978). Microbiotic crusts are also present in several areas across the Lost Forest.

A BLM Unit Resource Analysis (1980) described nearly half of this area (4,153 acres) as productive forest land, based on the ponderosa pine resource. Western juniper is the other significant tree species that is well-represented in the Lost Forest. The trees are irregularly spaced and stands are generally not dense. Berry (1963) measured the basal areas in the Lost Forest and found that ponderosa pine averaged about 30-35 square feet per acre over the 1,400 acres in the pine/big sagebrush and pine/bitterbrush communities. The highest basal areas for ponderosa pine (78 square feet per acre) were found in the sand dunes in the eastern portion of the forest. Western juniper is present in virtually all of the stands and ranges from five square feet per acre in the pine/big sagebrush community to a high of 50 square feet per acre in the community with Idaho fescue. Within the pine/bitterbrush community, the basal area for western juniper is 10 square feet per acre. On the pine dunes, Berry (1963) found that juniper occupied about 8 square feet per acre. Estimates of pine volume in the Lost Forest are quite variable, but a reasonable number seems to be 8 MM board feet, which would average 1,900 board feet per acre over the 4,135 acres of productive forest land (BLM 1980).

Two timber harvest entries have occurred in the Lost Forest. The first was in 1949 when 572,000 board feet were removed, primarily from the better pine sites in the central portion of the forest. The average volume harvested in the 1949 entry was 1.92 mbf/acre. The second sale in August 1953 covered 3,840 acres and included 1,622 mbf, with a modification the following year that added another 214 mbf to the total volume. This second sale covered most of the Lost Forest except for the far eastern part, with an average of 0.48 mbf removed per acre. At the time of the harvest entries, recently dead trees and older snags were felled in order to reduce the fire hazard from lightning strikes in the area.

The Lost Forest was designated by the BLM as a Research Natural Area (RNA) in 1972 in order to preserve this example of a relict ponderosa pine forest and to permit natural processes to predominate. In 1983 the Lost Forest as well as the Sand Dunes and Fossil Lake were formed into an Area of Critical Environmental Concern (ACEC). Also, in 1989, the Lost Forest was designated an Instant Wilderness Study Area (ISA). As such, this federally managed forest is protected on several levels.

Some significant tree mortality has occurred in the Lost Forest in the past. The severe drought of the 1920s and 1930s is believed to have contributed to the death of many western juniper and possibly some pine as well (Berry 1963). It is reported that there was extensive mortality in other areas of central Oregon due to the drought of the 1920s and 1930s combined with an increase of cedar bark beetles (Furniss and Carolin 1977). The two species of cedar bark beetles that have been recently reported in a similar forest are *Phloeosinus serratius* and *Phloeosinus* sp. In addition, there are many uprooted ponderosa pine on the ground, all in a fairly advanced state of decay. It is likely these occurred from an old windthrow event. In certain areas, recent mortality of ponderosa pine is fairly concentrated and appears dramatic, especially in light of the widely spaced stands that are common throughout the forest. The widely spaced stands of the Lost Forest appear to be fully occupying these low productivity sites.

As pines continue to discolor and die, the question has been raised about the overall health of the forested vegetation within the Lost Forest. In the spring of 2005 the Lakeview District of the Bureau of Land Management requested that the Central Oregon Forest Health Protection staff conduct an evaluation of the health of the Lost Forest and report the findings so that they could be incorporated into a new Management Plan that is scheduled to be prepared for the RNA.

The overall objectives of our work in the Lost Forest RNA (LFRNA) were to determine the current condition of the ponderosa pine component, identify potential future trends in that condition, and identify possible treatments or management actions that would promote natural processes in the LFRNA.

MATERIALS AND METHODS

A field sampling design was developed for gathering data on forest stand structure, tree species composition, seedling recruitment, forb, and shrub cover, and detrimental agents. The design was intended to provide answers to the following specific questions:

- What is the size class structure of ponderosa pine and juniper?
- Has juniper increased in density over the last 100 years?
- What are the roles of the shrub and juniper components and do they compete with ponderosa pine?
- What are the regeneration levels and patterns for ponderosa pine and western juniper and is the ponderosa pine population likely to be sustained in the LFRNA?
- What are the significant tree mortality agents?
- What is the mortality history of pine and juniper in the Lost Forest?
- What is the role of fire in the LFRNA?
- What were the effects of the harvesting in the 1940s and 50s?

In April and May 2005 we established 13 transects throughout the Lost Forest to collect information on individual tree and shrub attributes. The primary roads through the Forest were used to determine the starting points for each survey transect. The first transect was established a short distance east of the western boundary of the LFRNA and five additional transects were established at one-mile intervals along the main east-west road (Road 6151). Three additional transects were established along the north road (Road 6141-1); two others near the camping area in the northeastern corner of the Forest, and another two along the north-south road (Road 6141-A) midway through the Forest. All survey transects were oriented north and south and the starting and ending points were determined and recorded with a hand-held global positioning system (GPS). The locations of all 13 transects are shown in Figure 1. Each transect was 20 chains (1/4-mile) long and two chains wide (132 feet), giving a sampling area of four acres per transect (1 chain = 66 feet). Along each transect, a 1/10th acre fixed-area plot (37.5' radius) was established at five-chain intervals (located at chains 5, 10, and 15). These three plots were used to collect data on small trees (1.0" to 4.5' in height) and vegetative cover and to determine tree ages and growth rates on ponderosa pine and western juniper larger than 5" dbh.

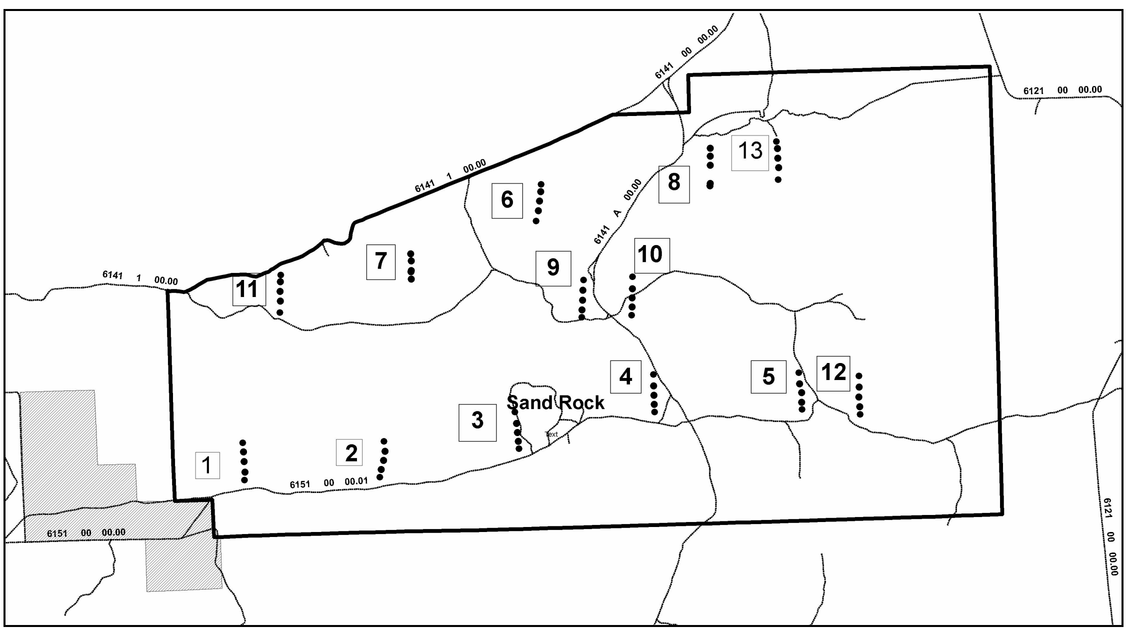

Figure 1. Locations of 13 survey transects within the Lost Forest RNA, April/May 2005.

All trees 4.5 feet tall and taller were measured along each transect for the following attributes: species, condition (live or dead), diameter at breast height (4.5' [dbh]) for ponderosa pine, diameter at 12" above root collar for western juniper, total tree height, height from the ground to the lowest live branch, live crown ratio as a percent of total tree height, damaging agents,

and age (for selected trees). For ponderosa pine greater than 5” dbh, we recorded the Keen’s crown class as a measure of tree vigor. (A detailed rationale and procedure for using Keen’s crown rating classes can be found in Appendix A). For dead trees we also noted species, snag decay class (1-5), and suspected mortality agents.

All western junipers were placed in one of two age categories (greater than or less than 150 years old) using the crown and bark characteristics described by Miller and others (2005) and aided by personal communication with Dr. Richard Miller. Junipers less than 150 years old have a fairly pointed crown with 2-6” of terminal branch leader growth and show minimal furrowing in the bark. After 150 years, the bark on junipers becomes deeply furrowed and the crowns show varying degrees of branch dieback, foliage loss, and loss of apical dominance (Miller and others 2005). Based on these criteria, the junipers shown in Figure 2 are examples of trees likely to have been estimated at >150 years old.

Figure 2. Two junipers with attributes of trees >150 years old (deeply furrowed bark, some branch dieback, and reduced leader growth).

We found that many of the western junipers had multiple stems at the ground line and typically had a significant amount of foliage missing from the crown due to branch dieback. In order to account for these two variables and adequately depict the site occupancy of junipers, we aggregated the stem diameters at the ground line and recorded them as if they were one main stem, given that in other juniper species, there is a correlation between basal stem diameter and crown competition factor. In order to characterize the crown, we recorded the percent of foliage present as compared to the full potential crown, given the particular branching structure and size of the sample tree.

For trees smaller than 5” dbh, but at least 4.5’ tall that occurred in each transect, we collected the following information: species, condition (live or dead), dbh, height, damaging agents, and live crown ratio. A tally was taken

along the transect of all trees 1-4.5' in height. These trees were tallied by species and condition (live or dead). More detailed information was collected for these smaller trees on the 1/10th acre fixed-area plot.

The 1/10th acre fixed-area plots were established primarily to survey for regeneration and to make detailed observations on shrub and forb cover. For seedlings in the plot, the species, condition (live or dead), height, distance from closest shrub, shrub species, and proximity to sand dunes were recorded. In addition, each ponderosa pine and at least one juniper >5" dbh in the fixed-area plot was cored at dbh to determine tree age and radial growth for the past ten years.

Along the transects, fire scars were recorded on standing trees and char was noted on down wood as indicators of past fire disturbance. Data were also collected on stumps within each transect in order to reconstruct the pre-harvest stand. We used inside bark diameter at stump height as a surrogate for outside bark diameter at breast height. We also noted tree species, presence of annosus root disease, and origin of the stump (lightning prevention, harvest, or wood cutting by the general public).

The percent cover of microbiotic crusts was measured along the transects and on the 1/10th-acre plots; however, their significance is still to be determined.

When we set up the transects, we believed that we were locating them in the three main vegetation types described by Berry (1963): *Pinus ponderosa/ Artemisia tridentata* (3 transects), *Pinus ponderosa/ Purshia tridentata* (3 transects), and *Juniperus occidentalis- Pinus ponderosa/ Artemisia tridentata* (7 transects). However, based on the prevalent understory shrub component, we reclassified the vegetation represented by the transects into four groups that are described in the Results and Discussion section.

Another important source of information was the Aerial Detection Survey, an annual collaborative effort between the State of Oregon and USDA Forest Service that is carried out to identify centers of insect and disease activity. A special flight was done over the Lost Forest in 2005 to identify and delimit the root disease pockets that are common throughout the area.

RESULTS AND DISCUSSION

Even though the 13 transects were originally grouped into the three most widely represented vegetative communities within the Lost Forest, we quickly recognized that there was a great deal of variability within the Forest and in the data from our transects. This variation may mean that more data should be collected before we cannot draw definitive conclusions. Nonetheless, we do have some interesting findings and we present them as partial answers to the questions that were raised about the health of the LFRNA.

The 13 transects can be grouped in four vegetation types: juniper-pine/low sage, juniper-pine/big sage-low sage, juniper-pine/big sage, and juniper-pine/big sage-bitterbrush to indicate the vegetative communities (Table 1).

Table 1. Vegetation communities as determined by transect data arranged from least productive to most productive.

Vegetation Code	Shrub Species	Common Name	Associated Transects
JUOC/PIPO/ARAR8	*Artemisia arbuscula*	Low sage	9
JUOC/PIPO/ARTRT/ARAR8	*Artemisia tridentata / Artemisia arbuscula*	Big sage/ Low sage	2, 3, 4, 11
JUOC/PIPO/ARTRT	*Artemisia tridentata*	Big sage	1, 5, 6, 7
JUOC/PIPO/ARTRT/PUTR2	*Artemisia tridentata / Purshia tridentata*	Big sage/ Bitterbrush	8, 10, 12, 13

All of the survey transects, including the ones on sand dunes, contained enough western juniper for juniper to be included in the vegetative description. Some of the transects fit into certain vegetation groups more readily than others. In some instances, more than one vegetative type occurred along the length of the survey transect. As such, the groupings (shown in Table 1) should not be taken as discrete divisions, but rather as a "best fit" for some variable information. Several examples can be highlighted to help describe the challenges of classifying the transects according to vegetation types: Transect 1, with ARTRT only occurring in one $1/10^{th}$-acre plot (36 plants), is grouped with Transects 5, 6, and 7 which all had tall, dense stands of big sage. On transects 3, 4, and 11 low sage is included with big sage as a site identifier even though ARAR8 only occurred in one of the three $1/10^{th}$-acre plots. On these transects there was greater incidence of low sage along the length of the transect itself than what was reflected in the fixed plots (Lucile Housley, botanist, Bureau of Land Management, 2005 pers. comm.). The big sage/low sage vegetative group indicates that soil depth is highly variable along the transects because ARTRT indicates deep soils whereas ARAR8 indicates shallow soils (Rick Miller PhD. plant community ecologist, Oregon State University, 2005 pers. comm.). We believe there were sufficient micro site differences to account for the presence of both species of shrubs along those transects. Transect 9, with a predominance of ARAR8, is a stand-alone transect even though it contains minor amounts of ARTRT and PUTR. The frequency of these shrubs was too low to be grouped with the four transects containing larger amounts of ARTRT and PUTR (Table 2). Transect 13 is grouped with the three transects having ARTRT/PUTR even though it contains ARAR8 on one $1/10^{th}$-acre plot and no ARTRT with the PUTR (Table 2). This transect had slowly moving dunes in the first $2/3^{rd}$ where shrub establishment was rare and a mixture of low sage and bitter brush in the last $1/3^{rd}$.

Table 2. Plant frequency for low sage (ARAR8), big sage (ARTRT) and bitterbrush (PUTR) in **three 1/10th-acre plots** along each transect. Frequencies were used to group the transects into vegetative types. Numbers beneath the plant codes indicate the total tally of the specified plants in the first, second, and third 1/10th-acre plots, respectively. Percent cover values are average shrub cover on the circular plots. Shrub species present were *Artemisia tridentata, Artemisia arbuscula, Purshia tridentata, Chrysothamnus visiciddiflora, Tetradymia canescens,* and *Ericmeria nauseosus*. M* = missing data

Vegetation Type	Transect #	Cover of shrubs (%)	ARAR8	ARTRT	PUTR
Low sage	9	14.67	61, 36, 54	3, 0, 3	1, 1, 2
Big sage/Low sage	2	31.83	15, 20, 38	67, 15, 22	
	3	22.49	0, 244, 0	53, 118, 608	
	4	83.81	0, 0, 209	70, 46, 0	
	11	25.09	0, 57, 0	11, 31, 27	
Big sage	1	9.38		0, 36, 0	
	5	67.41		93, 65, M*	
	6	65.22		100, 0, 45	
	7	117.67		47, 91, 56	
Big sage/Bitter brush	8	36.93	0, 1, 0	7, 25, 17	8, 5, 2
	10	105.43	5, 0, 0	113, 35, 19	51, 70, 23
	12	28.72		3, 0, 26	37, 31, 46
	13	39.06	0, 0, 74		0, 21, 38

For the purposes of analysis and display in tables and figures, the transects will be grouped in ascending order of site productivity from low sage to big sage/low sage to big sage to big sage/bitterbrush.

Size class structure and distribution of ponderosa pine and juniper

The data for the distribution of live and dead trees >4.5 feet tall are shown in Table 3 for each of the 13 survey transects. The summaries, expressed on a per-acre basis, show extreme variability between transects. As expected, the number of ponderosa pines per acre was greatest in the two transects in the sand dunes (#s 12 and 13) and in the two transects originally classified as being in the pine/big sagebrush community (#s 9 and 10). For pines, the live trees greatly outnumbered the standing dead trees on every transect (Table 3). Dead pines were most common on transects 12 and 13 on the eastern portion of the LFRNA, averaging over three per acre along transect 12. These two transects both had active sand dune movement. Elsewhere, there was generally less than one dead pine per acre (Table 3). Western junipers were very well-represented and outnumbered the pines on virtually every transect. For trees greater that 4.5 feet in height, juniper densities exceeded 30 trees per acre on nearly half of the transects whereas the highest pine density was 28 trees per acre (transect 13).

Table 3. Summary of survey transect data for live and dead ponderosa pine and western juniper trees **per acre** in the Lost Forest RNA, Summer 2005 (data do not include trees less than 4.5 feet tall).

Vegetation type	Transect	PIPO Live	PIPO Dead	PIPO Stump	JUOC Live	JUOC Dead	JUOC Stump
Low sage	9	14.5	0.5	2.5	47.25	3.5	0
Big sage/Low sage	2	0.75	0.5	1.25	21.75	6	1.5
	3	4	0.75	2.25	14.75	5	0.75
	4	1	0.5	0.25	10	2.75	0
	11	1.25	1.25	0.75	35	4.25	4.5
Big sage	1	5.75	0	0.25	13	1.75	0
	5	1.25	0.5	0.75	16	7.5	0.25
	6	3.75	0.75	1	36.5	8	2.25
	7	1	0.75	0	8.25	4.25	1.25
Big sage/Bitter brush	8	11	1	0.5	25.5	4.5	0
	10	19.75	0	1.25	18	2.25	0.25
	12	16.5	3.25	3.25	41	27.25	1.75
	13	27.75	1.75	3.25	31	7	1.5

The distribution of trees less than 4.5 feet tall is shown in Table 4. Again, as with the larger trees, there was a lot of variability in how these small trees were distributed. Only 133 smaller pines were found on the 52 acres that constituted our survey and over one-third of them were found along transect 13 on the dunes in the northeastern corner of the Forest (Table 4). The next highest concentration of small pines was in transect 10, in the heart of the pine/big sagebrush community. There was less than one small pine per acre on nearly half of the transects, indicating that pine recruitment is not particularly high in a large portion of the LFRNA. Junipers less than 4.5 feet tall were much more common than small pines on every transect except transect 1 (Table 4). Even in the transects associated with dunes (#s 5, 8, 12, and 13) where pines seem to thrive, the small junipers were at least three times more common than small pines (Table 4).

Table 4. Summary of survey transect data for live and dead ponderosa pine and western juniper seedlings and trees **less than 4.5 feet tall/acre** in the Lost Forest RNA, Summer 2005.

Vegetation type	Transect	PIPO Live	PIPO Dead	JUOC Live	JUOC Dead
Low sage	9	1.25	0	20	0
Big sage/Low sage	2	0	0	9	0.25
	3	0.5	0	6.5	0.5
	4	0	0	2.5	0
	11	0.5	0	16.5	0
Big sage	1	1.75	0	0.75	0
	5	0.75	0	6.5	0
	6	3.5	0.25	9.5	0
	7	0.25	0	3	0.25
Big sage/Bitter brush	8	4.75	0	12	0
	10	6.25	0.5	16.5	0.25
	12	2	0.25	12.5	0
	13	11.75	0.25	31	8.75

Figure 3 shows the comparative stocking levels of ponderosa pine and western juniper in terms of basal area, expressed in square feet per acre. Junipers dominate the area not only in trees per acre, but also in basal area on every transect except transect 10. Although most of the juniper stands are fairly open, there were two transects where juniper density exceeded 100 square feet of basal area per acre on the northern edge of the Lost Forest (transects 6 and 11, Figure 3). These basal areas are higher than those reported for juniper by Berry (1963), and simply serve to indicate the high level of variability within the Forest when compared with the other transects (Figure 3). Our transects did not pick up the high densities of pine (70+ square feet per acre) that Berry (1963) reported in the sand dunes, and most transects showed less than 20 square feet of pine per acre (Figure 3). The highest basal area for ponderosa pine (37 square feet per acre) was found east of Road 6141-A near the center of the Lost Forest on transect 10. In general, the pine densities were higher in the big sage/bitterbrush type than in the other vegetative communities (Figure 3).

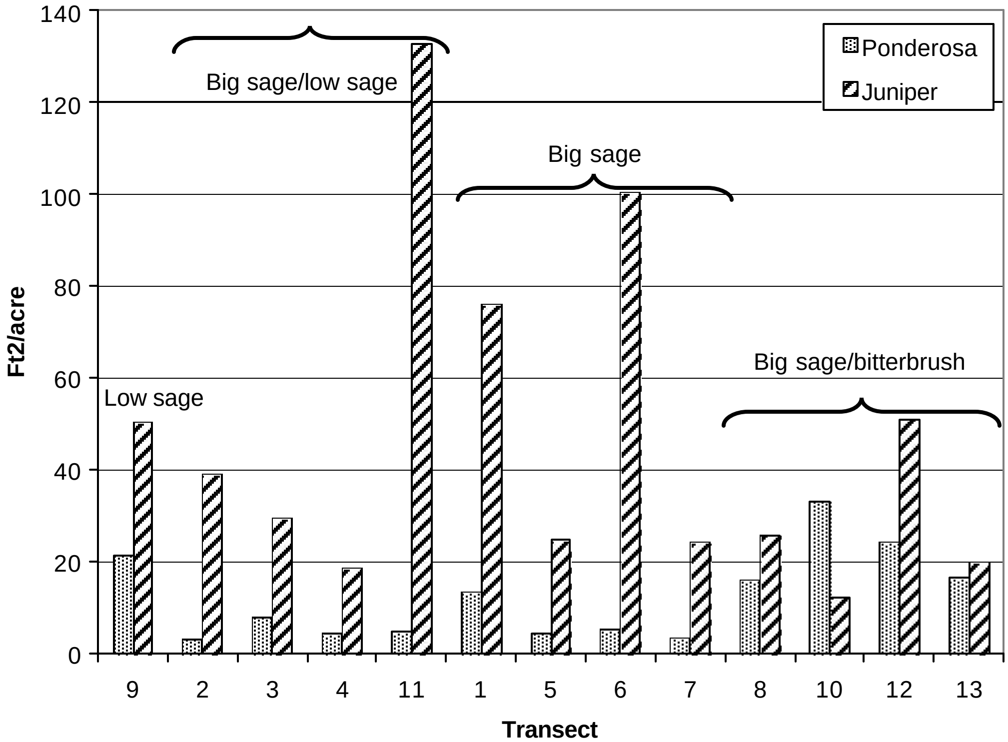

Figure 3. Basal areas of ponderosa pine and western juniper along 13 survey transects in the Lost Forest RNA. April/May 2005

The distribution of diameters for ponderosa pine is shown in Figure 4. Aside from the typical variability that characterizes the pine and juniper stands throughout the Lost Forest, it is interesting to note that each transect (and each vegetative group) had some pines greater than 30" dbh (Figure 4). Trees 20-30" dbh are also well-represented, especially in the big sage/ bitterbrush vegetative type, where there were four to five trees per acre. Pines in the 10-20" dbh range were also fairly well-represented on most transects, especially in the low sage and big sage/bitterbrush transects (Figure 4). The broad range of tree sizes that occurs in the Lost Forest indicates that younger, smaller trees are available to replace older dominant pines in the future. The average diameters of pines are shown by transect in Appendix B.

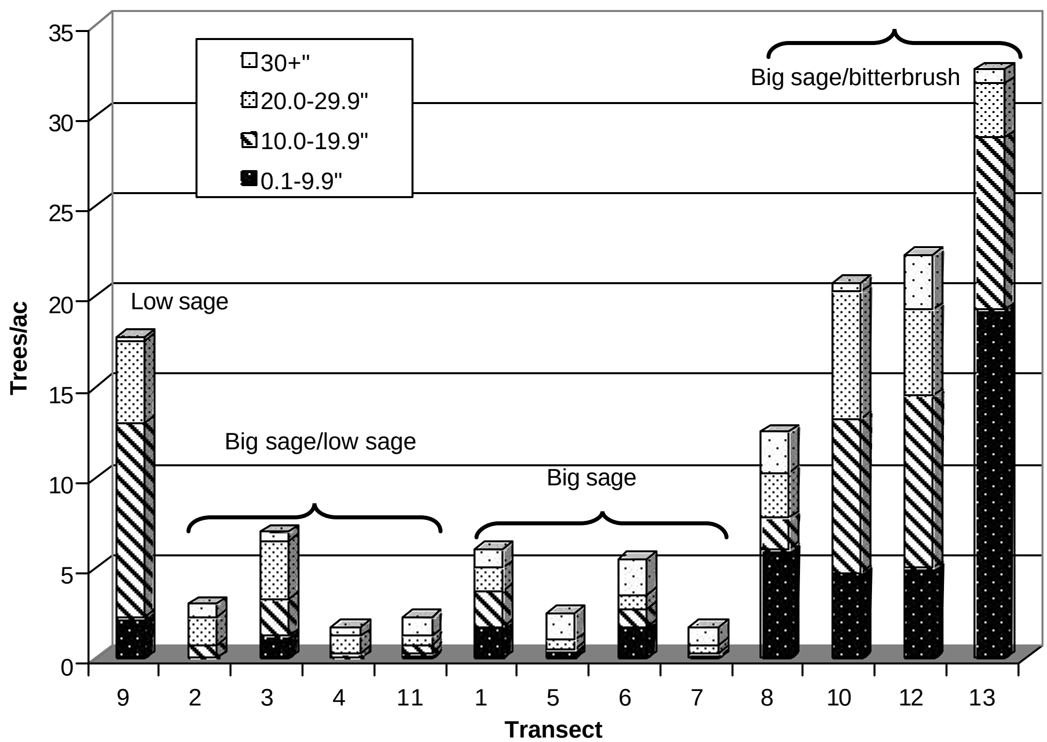

Figure 4: Diameter distribution of ponderosa pines >4.5 feet tall along survey transects in the Lost Forest RNA. April/May 2005.

The overall health of the ponderosa pine component in the LFRNA can be characterized not only by the age class structure but also by the condition of existing trees. The Keen's crown class categories were used to make this assessment (see Appendix A for details). The rating system places crowns of ponderosa pine into four classes, A through D, based on their fullness and vigor. An "A" crown is the most vigorous and its length is greater than 50% of the total tree height. A "D" crown is very sparse and indicates poor tree health. Within the Lost Forest RNA, 80% of the pine crowns were classified as either "A" or "B" (130 each), indicative of healthy, vigorous trees. Only 56 trees (17% of the total) were rated as having a "C" crown, and half of those were found on a single transect (Transect 9) which occurred on the poorest sites (Figure 5) and had the highest juniper density with 47/acre (Table 3) . This is a very encouraging finding, and compares favorably to the crown class distribution in a virgin pine forest where Keen tested his risk rating system. In a sample of over 22,000 ponderosa pine trees in southern Oregon, Keen (1936) found that 70% of the crowns were rated "A" and "B" and 22% were rated "C". Trees with "A" and "B" crowns were much less likely to be infested by bark beetles than trees with lesser "C" and "D" crowns (Keen 1936). Based on this crown rating factor, it is fair to conclude that the overall vigor of ponderosa pines in the relict Lost Forest is not unlike the vigor of pine in other forests in southern Oregon. Most of the pines in the LFRNA are at relatively low risk to bark beetle attack and are growing vigorously.

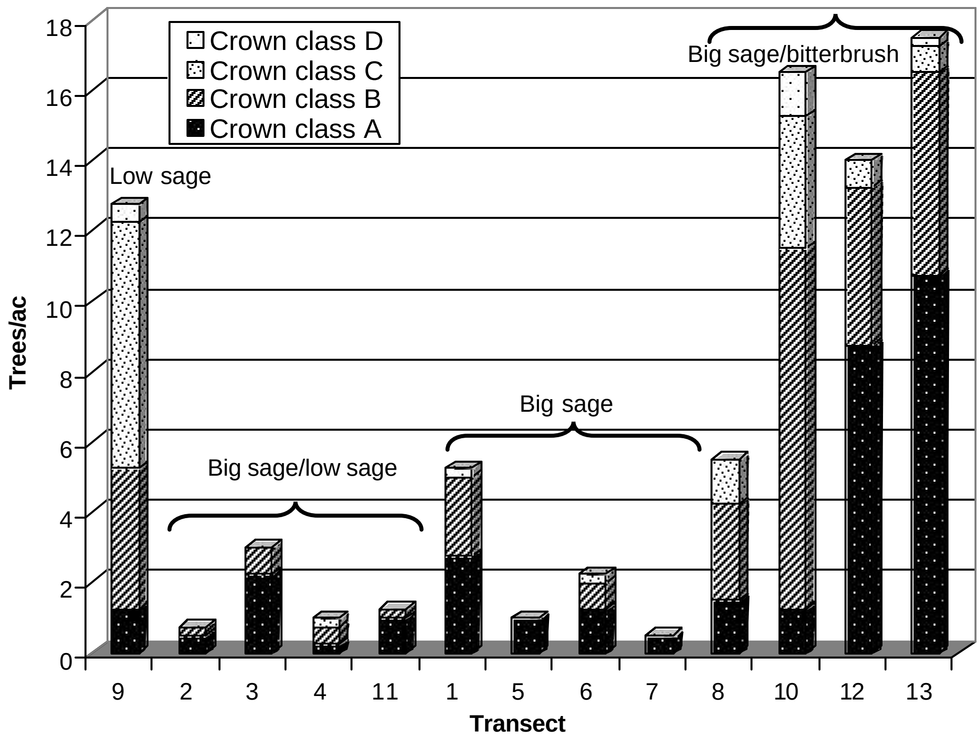

Figure 5: Keen's crown class ratings for ponderosa pines >5" dbh along survey transects in the Lost Forest RNA. April/May 2005 ("A" denotes vigorous crown; "D" denotes poor crown and low tree vigor).

Tree vigor can also be expressed in terms of radial growth rates. These growth rates can be indicative of how fully a site is occupied and whether or not inter-tree competition is occurring. For ponderosa pine, the threshold for inter-tree competition has been shown to be at the point where a tree is adding 1.5 inches of diameter growth in a decade (Cochran 1992), or at most 13 annual rings in the last inch of radial growth. The stand density at which this threshold of growth occurs will vary according to the quality of the site. Silviculturists commonly express this growth rate in "20^{ths}" of an inch which would be the amount of radial growth over the last ten years, measured in 20^{ths} of an inch. This number can be doubled for diameter growth. In other words, ¾-inches of radial growth in a decade would be expressed as $15/20^{ths}$ of radial growth and would constitute the threshold for competition-free growth. Any pine growing at $15/20^{ths}$ or greater radial growth would be considered vigorous (with 1.5 inches of diameter growth per decade) and not likely to experience the effects of competition for resources. A comparable threshold growth rate has not been determined for western juniper, but the growth is expressed here in the same terms for purposes of comparison with the growth rates of ponderosa pine. Only 61 trees (36 pines and 25 junipers) were available for growth-rate determinations on the fixed-radius plots. The data are shown by transect in Appendix C. Ponderosa pine growth rates were lowest on transect 9 (low sage community) where soils were compacted

(Desi Zamudio, soil scientist, USDA Forest Service, 2005 pers. comm.). On this poor site, pines were growing at an average of only 5/20ths, well below the desired threshold. Two specific examples can be used to highlight the poor growth on transect 9: a 130-year-old pine measuring 13.5" dbh was growing at 7/20ths despite a live crown ratio of 55% and a Keen's crown class of 2B, while another pine measuring 15.5" dbh and 281 years old was growing at 4/20ths. Pine growth was considerably better on the big sage/low sage sites, ranging from 3/20ths to 39/20ths with an average growth of 19/20ths for six trees. Growth rate on the big sage sites was slightly lower for four trees, with an average of 13/20ths which is just below the desired threshold. The pine growth was slow on the eight trees along transect 10 (6/20ths), but was quite good elsewhere on the dune sites (big sage/ bitterbrush community) and averaged 15/20ths. In general, there was considerable variation in the pine growth rates within each of the vegetative communities, but it is important to note that many individual trees were growing exceptionally well, especially on the dune sites (Appendix C). For example, on transect 5, a 95-year old pine (35.9" dbh) was growing at 23/20ths and the tree with the best growth (39/20ths on transect 11) was only 30 years old and measured 14" dbh. The only pine growth rates of concern were the ones associated with the low sage site (transect 9). By comparison, the radial growth rates of western juniper were less variable but considerably lower than those for pine (Appendix C). Two junipers along transect 5 (big sage community) averaged 15/20ths, but most of the other growth rates were around 5 to 6/20ths.

Juniper increases in density over the last 100 years

As shown in Figure 6, there were more junipers under the age of 150 years old than over 150 years old. For junipers greater than 4.5 feet tall, 60% were estimated to be younger than 150 and 40% were older. If the 588 junipers less than 4.5 feet tall are added in, then the distribution is skewed even further toward the younger trees (72.5% younger than 150). Nonetheless, three of the 13 transects had substantially more old than young junipers, indicating a greater degree of stability in the juniper resource than the other transects where ingrowth appears to have been significant in recent years. These three transects (#s 1, 6 and 11) were located in the low sage/big sage and the big sage vegetation types. By comparison, Miller and Rose (1999), studying juniper woodland development in the Chewaucan River basin, found that presettlement junipers (trees older than 130 years) accounted for less than 1% of the total juniper population. Similarly, the juniper encroachment in the Steens Mountains was found to have occurred primarily in the past 100 years and few trees were found that predated European settlement in the late 1800s (Miller and Rose 1995). These studies closely mirror the findings of Gedney and others (1999), who report a five-fold increase in the western juniper resource between 1936 and 1988 for eastern Oregon. In contrast, there has been a significant population of junipers in the Lost Forest for a long time. At least five of our survey transects (covering all vegetation types)

would have had more than 10 junipers per acre in the early 1800s and three of them would have had more than 15 trees per acre (Figure 6). Nonetheless, juniper recruitment currently appears to be very significant throughout the Lost Forest in every vegetation type.

The two extremes in juniper ages in the LFRNA are represented by transects 1 and 13. In the southwestern corner of the RNA (transect 1), there was very little recruitment of young junipers where the sand appeared to have stabilized and little juniper mortality had occurred. In the northeastern corner (transect 13) where dunes appear to be more active, the vast majority of the junipers were young and very few older trees were found (Figure 6). This transect also had the highest level of mortality in young juniper (Table 3).

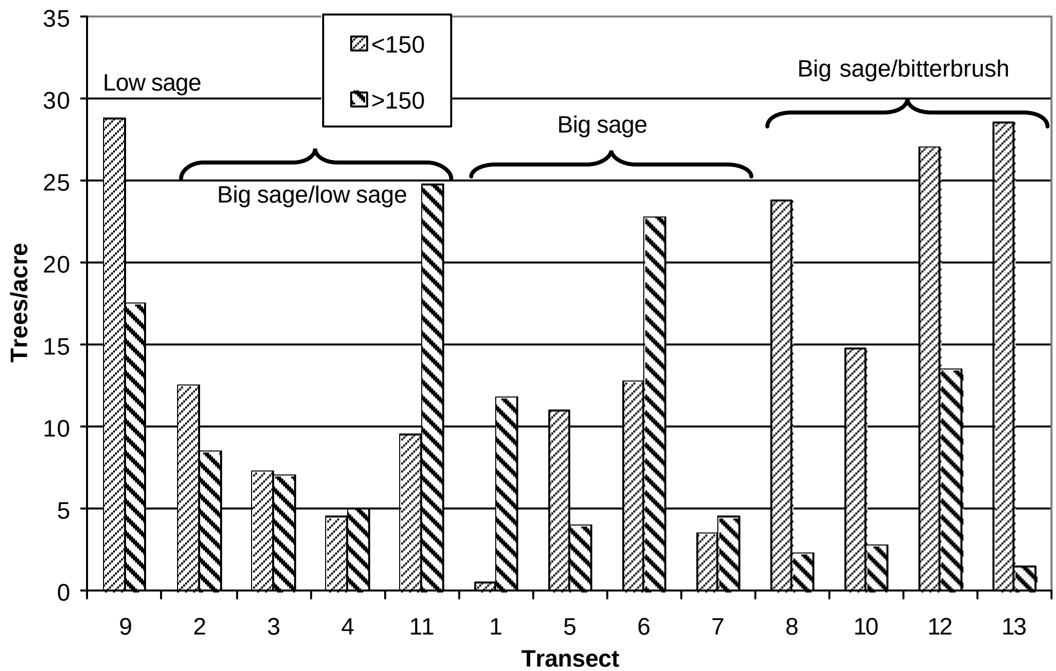

Figure 6: Age classes of western junipers >4.5 feet tall along survey transects in LFRNA. April/May 2005.

Roles of shrub and juniper components as competitors with pine

Gedney and others (1999) estimated that juniper roots may extend out from the main stem from one to 2.5 times the tree height. For trees averaging 25 feet in height (a number derived from the 1988 inventory of juniper), if lateral roots extended out 40 feet, site occupancy would occur at only nine trees per acre (Gedney and others 1999). Based on this type of criterion, the entire area would be considered fully occupied by western juniper. However, we believe this is not applicable to the Lost Forest. There were other indicators that there is not full site occupancy. These indicators include an

abundance of shrubs that appear very healthy, good growth rates on ponderosa pine, and a large number of small healthy pine and juniper on site.

As juniper woodlands develop and trees begin to dominate the site, there is typically a loss of vigor and dieback among the shrubs (Miller and others 2005). The only evidence of dieback on big sage was defoliation produced by the aroga moth, *Aroga websterii*, a small insect that feeds on the foliage of several species of *Artemisia* and is presently at high levels in the Christmas Valley (Miller 2005). In the Lost Forest, the final stages of woodland development may not produce the >30% juniper cover that Miller and others (2005) describe for much of the juniper distribution in eastern Oregon. Nonetheless, it appears from our data and observations that juniper densities are still increasing in the Lost Forest even though they are above the threshold that Gedney and others (1999) describe.

Regeneration levels and patterns of ponderosa pine and juniper

Only 70 ponderosa pine and western juniper seedlings and saplings less than 4.5 feet tall were found on the 39 1/10th-acre plots within our survey transects. Western juniper was considerably more numerous than ponderosa pine (54 JUOC and 16 PIPO). Small juniper was fairly evenly distributed across all of the vegetation types except the low sage, where only one seedling was recorded. In contrast, virtually all of the small pines were found in the big sage/bitterbrush community and the majority of those were from transects 12 and 13 in the eastern portion of the Lost Forest where dunes are an important feature. In general, we noted more regeneration of both ponderosa pine and western juniper than Berry did in 1963. Berry was unable to determine the number of seedlings per acre due to their clumped distribution. He observed that “seedlings could be found in only limited areas in which especially favorable moisture and cover prevailed.” He also noted that ponderosa pine seedlings were most commonly encountered under gray rabbit brush (*Chrysothamnus viscidiflorus*) and were not found associated with any other shrub. Our findings were somewhat different, as shown in Table 5 where we describe the variables associated with the distribution of small pines and junipers.

Table 5: Relationship between the incidence of pine and juniper regeneration (trees <4.5 feet tall) and presence of shrubs on 1/10th-acre plots along survey transects, LFRNA, April/May 2005.

Setting	PIPO seedlings	JUOC seedlings
With shrub	2	25
On dune	9	4
On dune with shrub	1	6
Alone	4	19

Only three of the 16 ponderosa pine seedlings were within microsites clearly influenced by shrubs. Various plants were involved in this site modification and included prickly flox (*Leptodactylon pungens*), bitterbrush, and western juniper. More small pines were found on dunes than in any other setting. Juniper was less strongly associated with dunes than was ponderosa pine, and was often found within sites modified through the influence of a shrub or tree (Table 4). As in the case with pine, the small juniper was associated with a variety of shrub species.

Significant mortality agents in the LFRNA

The most important mortality agent for ponderosa pine in the Lost Forest RNA is clearly annosus root disease, caused by the fungus *Heterobasidion annosum*. In virtually every case where we found dead ponderosa pine (even when killed by the western pine beetle, *Dendroctonus brevicomis*, there was at least the circumstantial evidence that suggested annosus root disease as the primary cause of death. This evidence includes old pine stumps that initially served as infection courts for the root pathogen, nearby dead juniper (also susceptible to the same pathogen), and a number of other dead trees that died in previous years as the pathogen grew through the roots of stumps and infected the roots of standing trees. In many cases the earliest trees to die from the initial infection have lost their tops or have blown over from root failure, creating a distinctive "pocket" or opening in the stand. These distinct openings serve as a signature for recognizing and mapping annosus root disease (Figure 7).

Figure 7: Typical pocket of tree mortality caused by *Heterobasidion annosum*, annosus root disease. The pocket is characterized by presence of snags of different ages and currently discoloring trees along the edges.

The extent of annosus root disease within the Lost Forest is shown in Figure 8, in a map derived from the aerial detection survey conducted in August of 2005. The 17 polygons marked as "RD" represent pockets with the root disease signature and the numbers following them indicate the number of pines with currently discoloring crowns along the edges of the polygon. Typically, these polygons need to be at least two acres in size before they can be detected from the air. As such, it is likely that there are additional smaller pockets of root disease in the area. Although an analysis of

vegetation type was not done, it appears that many of these root disease polygons occur in areas with sand dunes and/or big sage.

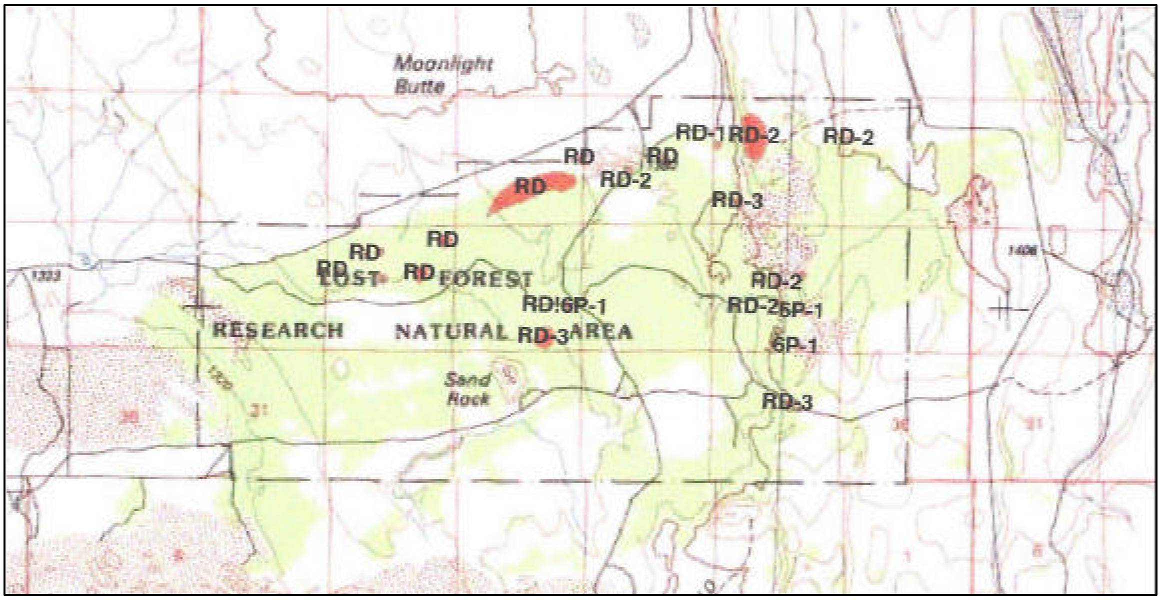

Figure 8. Locations of annosus root disease pockets in the Lost Forest as recorded from August 2005 aerial detection survey.

The root disease was able to become widespread throughout the Lost Forest from essentially a single harvest entry in the 1950s. The pathogen continues to kill pine and juniper after 50 years with little indication of it dying out. This persistence is probably due to the large-tree structure that remained after the timber harvest and aided by the fact that both pine and juniper are susceptible to the disease. Several of the survey transects either intercepted some of this root disease-related mortality or came within a short distance of the pockets created by the pathogen. One example is found in transect 12 which shows over 27 dead junipers per acre and over 3 dead pines per acre (Table 3). Many of these dead trees were in settings that are classic indicators of annosus root disease (proximity to old stumps; dead pines nearby; a progression of mortality over time).

When Dr. Don Knutson, plant pathologist from Oregon State University, visited the Lost Forest in 1975, he attributed some of the pine mortality to Armillaria root disease. We found no evidence of that pathogen in our survey and we believe that annosus root disease is the agent most directly involved in pine and juniper mortality in the classic root disease pockets.

During that same field visit, Dr. Knutson also reported evidence of the needle disease *Elytroderma deformans*, which sometimes produces brooms in its pine host once infections become systemic (Figure 9). We found evidence of

this pathogen as well, but only on a few pines. In central Oregon, the impacts of *Elytroderma* on the host are generally minimal and are typically associated with areas of high humidity.

Figure 9. Broom caused by the needle pathogen *Elytroderma deformans.*

Dr. Knutson also stated that porcupines were responsible for the death of numerous small pines. While we did observe some evidence of porcupine damage on our transects, the effects were limited to minor wounding and occasional top-kill, with very little tree mortality attributed to them. In total, we noted porcupine damage on only 13 trees. All of the damaged trees were pines and were widely scattered throughout the Forest, without any apparent affiliation to a particular vegetative type. None of this porcupine damage appeared to be recent.

Although the movement of the sand dunes is most significant to the south of the Lost Forest, there has been some sand moving through the forest itself. This dune movement has probably been an important mortality factor for both pine and juniper over the years. Transect 13 was in the only area where we noted recent mortality from dune movement in both pine and juniper.

Mortality history of pine and juniper in the Lost Forest

Some early reports such as the work of Berry (1963) suggest that there was a significant die-off of western juniper in the LFRNA during the drought of the 1920s and 1930s. That would be consistent with similar reports for other areas in central Oregon during that time period where high levels of juniper mortality were noted (Furniss and Carolin 1977). While we were not able to verify the timing of the juniper mortality in the LFRNA, Berry's estimates seem reasonable and perhaps could be verified through addition analysis of tree rings. There may be selected surviving pine or other juniper that benefited from the release from competition and their radial growth response might provide a good

Figure 10. Symptom of branch dieback from unknown causes that has been commonly seen in recent years on western juniper in central Oregon. Transect 2, LFRNA, 2005.

indication of when the juniper died. More recently, there has been significant branch dieback in the younger junipers throughout central Oregon (Figure 10). The cause of this juniper dieback still remains unknown, but biotic agents do not appear to be responsible. This symptom of partially brown crowns was very common throughout the southwestern portion of the Lost Forest and was recorded on some of our transects. Typically, the loss of foliage is not extreme (rarely more than half the crown is involved) and whole-tree mortality is uncommon. Additional die-off of junipers is very likely linked to annosus root disease, based on the pattern of its occurrence. In numerous instances, both on and near our transects, we found small groups of dead junipers (two to ten trees per group) of all sizes, near old pine stumps from the harvest entry of 1954. Typically there were dead pines in the group as well, giving additional evidence for annosus root disease as the primary cause of the mortality in western juniper.

Ponderosa pine mortality was also noted by Berry (1963) and was believed to have occurred during the drought of the 1920s and 1930s. He remarked that the drought at that time was the most severe in several hundred years, and would certainly have placed a great deal of stress on trees, making them vulnerable to bark beetles. We do not know if there is a connection between the pine mortality noted by Berry (1963) and the high number of uprooted pines that we found throughout the Lost Forest in our survey. Because all of the down trees were in an advanced state of decay, we were not able to assign a date to the disturbance that would have produced them, but they could easily have been on the ground for 70+ years. Some of them may have been windthrown beetle-killed trees, but we believe that most were probably live trees brought down by a significant wind event because virtually all are oriented in the same general direction and appear to be similarly aged. Figure 11 shows two of the down ponderosa pines with the one in the foreground more significantly deteriorated than most of the down trees we observed. The general level of deterioration was comparable to the boles of the snags that had been felled in the 1950s for fire hazard reduction.

Figure 11. Root wads of old windthrown ponderosa pine commonly seen along survey transects, LFRNA, April/May 2005.

The overall distribution of down material is shown in Table 6. The number of large down pines was particularly high in five of the transects, where over seven windthrows per acre were recorded (Table 6). There were also high numbers of western junipers on the ground, but not necessarily in the same areas as the down ponderosa pine. Table 6 shows that transects 9 and 12

had high numbers of both juniper and pine on the ground. Ponderosa pine windthrow appeared to have been more common in the central and southern portions of the Lost Forest while juniper windthrow was most abundant in the central and southeastern portions (Table 6). Windthrows of both species were considerably less common in the northern transects, although they did occur. For the transects with the highest numbers of pine on the ground, the basal areas involved were around 20 square feet per acre, a substantial amount compared to the current standing basal areas which are fairly low for pine (Figure 3). There did not appear to be a link between windthrow and vegetation type.

Table 6. Summary of survey transect data for **down** ponderosa pine and western juniper **per acre** in the Lost Forest RNA, with average diameters in inches estimated just above root collar Summer 2005.

Veg. type	Tran	Species	Stems/ acre	Average Diameter	Min. Diameter	Max. Diameter	Standard Deviation
Low sage	9	juniper	8	12.97	4	30	5.75
		ponderosa	9.75	18.31	8	38	6.51
Big sage/Low sage	2	juniper	4	17.38	6	40	9.63
		ponderosa	7.25	22.66	8	36	6.85
	3	juniper	5	21.3	9	38	8.63
		ponderosa	9	21.61	3	42	7.65
	4	juniper	8.75	14	5	40	7.19
		ponderosa	2.5	22.4	13	34	6.24
	11	juniper	0.5	12.5	8	17	6.36
		ponderosa	1	31	16	40	10.89
Big sage	1	juniper	1.5	13	6	31	9.21
		ponderosa	0.5	29	25	33	5.66
	5	juniper	9	19.33	6	38	9.86
		ponderosa	5.25	30.43	14	45	8.98
	6	juniper	2.25	15.22	5	36	10.26
		ponderosa	2.5	32.1	12	46	11.66
	7	juniper	5.75	27.61	11	50	11.98
		ponderosa	2.25	35	27	48	6.84
Big sage/Bitter brush	8	juniper	0.25	7	7	7	
		ponderosa	2.5	26.6	16	36	6.24
	10	juniper	4	9.88	5	17	3.93
		ponderosa	7.5	18.63	12	30	5.03
	12	juniper	7.75	16.39	4	65	14.03
		ponderosa	8.75	22.23	12	42	7.13
	13	juniper	0.5	19	14	24	7.07
		ponderosa	3.25	30.46	16	38	6.96

The effects of annosus root disease probably began to be expressed about 20 years after the first harvest entry of 1949. Typically, the fungal spores

colonize freshly cut stumps and the fungus grows through the root system of the stump until it comes in contact with grafted roots of live trees. When Dr. Knutson visited the Lost Forest in 1975, he was already seeing the first effects when he reported “pockets of dead pine and juniper.” Trees continue to die from annosus root disease to this day, as we found several pines with discoloring crowns and another with a green crown that was windthrown with severely decayed roots (Figure 12). We believe that additional trees currently green are also infected with annosus root disease and may discolor and die in the years to come.

Figure 12. Recently windthrown ponderosa pine with roots decayed by *H. annosum* root disease, LFRNA, 2005.

The role of fire in the LFRNA

We recorded evidence of fire in the form of lightning scars, basal fire scars, or charcoal on only 38 standing trees within our survey transects. Even though the incidence was widely noted (on all transects 6 through 13), 16 of the 38 trees were on transect 8. (It is important to point out that a road to a campground bisects this transect and as such, human activity may be related to the origin of some of these fires). There was suspected additional charcoal on some down material and on some old hollow stumps but we were less confident in our interpretation of these signs. Nonetheless, it is important to note that there was no aggregation or grouping of trees with clear signs of fire, confirming the idea that although lightning strikes might be frequent, there is little fuel available to carry them to any great extent. From our observations, we felt that in the recent past (the last 100 years), fire has not had a significant role in how these forests developed.

What were the effects of the harvesting in the 1940s and 50s?

Pine and juniper stumps were found at low densities throughout the Forest, generally less than one per acre on most of the survey transects. The highest density of juniper stumps (4.5 per acre) was on transect 11 in the northwest corner of the Forest, where there is easy access by road. We attribute these stumps to private woodcutters. The incidence of pine stumps was greatest in the areas where pine volume is greatest (the sandy sites represented by transects 12 and 13). In these areas we recorded about 3.5 stumps per acre (Table 3). Those numbers are shown again in Table 7, together with their associated diameters. Trees with diameters in the low to high-20s would yield volumes of 700 to 1100 board feet per tree, so that less than one tree per acre needed to be removed in order to derive the average of 0.49M board feet per acre that constituted the timber harvest of the early 1950s. Live pines in the survey transects were five to ten times more numerous than the stumps, indicating that even in the areas most heavily logged, the harvest entry of the early 1950s probably did not have a large effect on stand structure.

Table 7. Stump diameters for ponderosa pine stemming primarily from harvest entry in the early 1950s. Lost Forest RNA, 2005.

Veg	Transect	N/Acre	Avg. diameter	Min diameter	Max diameter	Std. Dev.
Low sage	9	2.5	20.32	13	31	2.5
Big sage/Low sage	2	2	22.5	9	36	2
	3	2.25	25.93	18	36	2.25
	4	0.25	19	19	19	0.25
	11	0.75	23.33	18	30	0.75
Big sage	1	0.25	25	25	25	0.25
	5	0.75	35.33	22	54	0.75
	6	1	39.5	27	59	1
	7	0				
Big sage/Bitter brush	8	0.5	24	24	24	0.5
	10	1	24.75	18	30	1
	12	3.25	27.38	18	46	3.25
	13	3.25	21.85	16	32	3.25

RECOMMENDATIONS FOR FURTHER STUDY

A number of interesting questions arose during our survey work and we believe that several of them merit further investigation. Some of this future work could be conducted by our Forest Health Protection staff, while other topics might better be investigated by someone else. Much of the proposed work would involve tree ring analysis, either to assign dates to certain events or to compare growth rates of trees in different settings. The following is our list of some further studies that would shed additional light on the processes occurring within the LFRNA:

1. Mapping annosus root disease pockets to follow the rate of spread of the pathogen.

At least two important factors make the Lost Forest RNA a very unique opportunity for the study of the dynamics of the spread of annosus root disease. The combination of no recent harvest entry and the wide spacing of host trees is unlike most situations under which the root pathogen occurs. Typically, pine stands on both public and private land have had many harvest entries, including recent ones, and there have been many new infection courts for fungi created in the process. In the case of the Lost Forest, we are seeing how dramatic the effects of this disturbance agent can be from what is essentially a single harvest entry. The spread rates, past and current, could be determined by stem-mapping the live and declining trees and stumps, and then coring the dead trees and snags to determine when they died. The progression of crown symptoms could also be monitored in green trees suspected of being infected by *H. annosum*.

2. The competitive abilities of western juniper and ponderosa pine on different sites within the LFRNA.

Our initial results suggest that ponderosa pine performs better than western juniper on the sandy soils but that western juniper has an advantage on heavier soils and harsher sites. There are many opportunities within LFRNA to test this hypothesis by coring pairs of similarly-sized pines and junipers growing closely together and comparing their growth rates under different site conditions.

3. Determine the timing of juniper mortality.

In our work, we were unable to assign a date to the concentrated juniper mortality that is evident in the western portion of the LFRNA and that was reported by Berry in 1963. The assumption has been made that a lot of juniper mortality occurred in the drought of 1920s and 1930s however, this has not been documented. Tree ring analysis would once again be appropriate to answer this question.

4. Timing of ponderosa pine blowdown event(s).

Our surveys revealed what seems to be a very large number of old windthrown pines. In localized areas it appeared that there were more pine stems on the ground than standing. Due to the advanced state of decay it was not possible for us to determine if these trees had come down in one major disturbance event or if several smaller disturbances had occurred. We felt that there were at least two events, one old and another even older. There may be opportunities to select old standing trees near windthrows and core them to look for release from competition as indicated by wider growth rings. One of the significant questions to be answered would be if there was any connection to the harvest entry of 1954 and the subsequent blowdown.

5. Modeling of fire behavior.

We collected information on distance from the ground to the lowest live branch on ponderosa pine and we have that data available for any modeling effort for fire behavior that might be undertaken for the LFRNA.

6. Further work to determine fire history.

Although we attempted to collect data on the evidence of fire along our transects, we were not able to make determinations of fire frequency within the Lost Forest.

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Appendix A

Tree vigor classes for ponderosa pine

In the early 1900s, foresters and entomologists recognized that the trees susceptible to bark beetles were usually weaker, less vigorous, and often older than ones more resistant to attack. There were several early efforts made at describing the specific characteristics that were associated with tree susceptibility, culminating in a system developed by F. P. Keen in 1936. Keen's system describes the array of crowns in ponderosa pine incorporating the variables of age, size and degree of dominance. The result of the crown rating system is a matrix with two axes; one of age and one of crown vigor (a function of the crown size and degree of dominance). Class 1 includes young trees less than 75 years old and rarely over 20 inches in diameter. Class 2 (immature) applies to trees 75 to 150 years old, rarely over 30 inches in diameter. Mature trees (150 to 300 years of age) are in Class 3, and Class 4 includes overmature trees more than 300 years old. Keen (1936) advises that because trees must be judged on external appearance rather than precise ages, they should be placed in the relative category that best fits their outward characteristics and appearance. The distinction between Class 1 and Class 2 is based on the color and roughness of the bark. Class 1 trees have the rough black bark typical of juvenile growth, while trees in Class 2 narrow plates begin to appear between the bark fissures. Distinctions between Classes 3 and 4 are more difficult to make, and require a look at the crowns as well as the bark (Keen 1936).

The second axis uses crown size and abundance of foliage as an indicator of tree vigor and includes the following descriptions, taken from Keen (1936):

Class A: Full, vigorous crowns, with a length of 55% or more of the total height, and of average width or wider; foliage usually dense; position of tree isolated or dominant (rarely codominant); diameters large for age

Class B: Fair to moderately vigorous crowns with average width or narrower, and less than 55% of the total tree height; either short wide crowns or long narrow ones, but neither sparse nor ragged; position, usually codominant but sometimes isolated or dominant; diameters above average for age

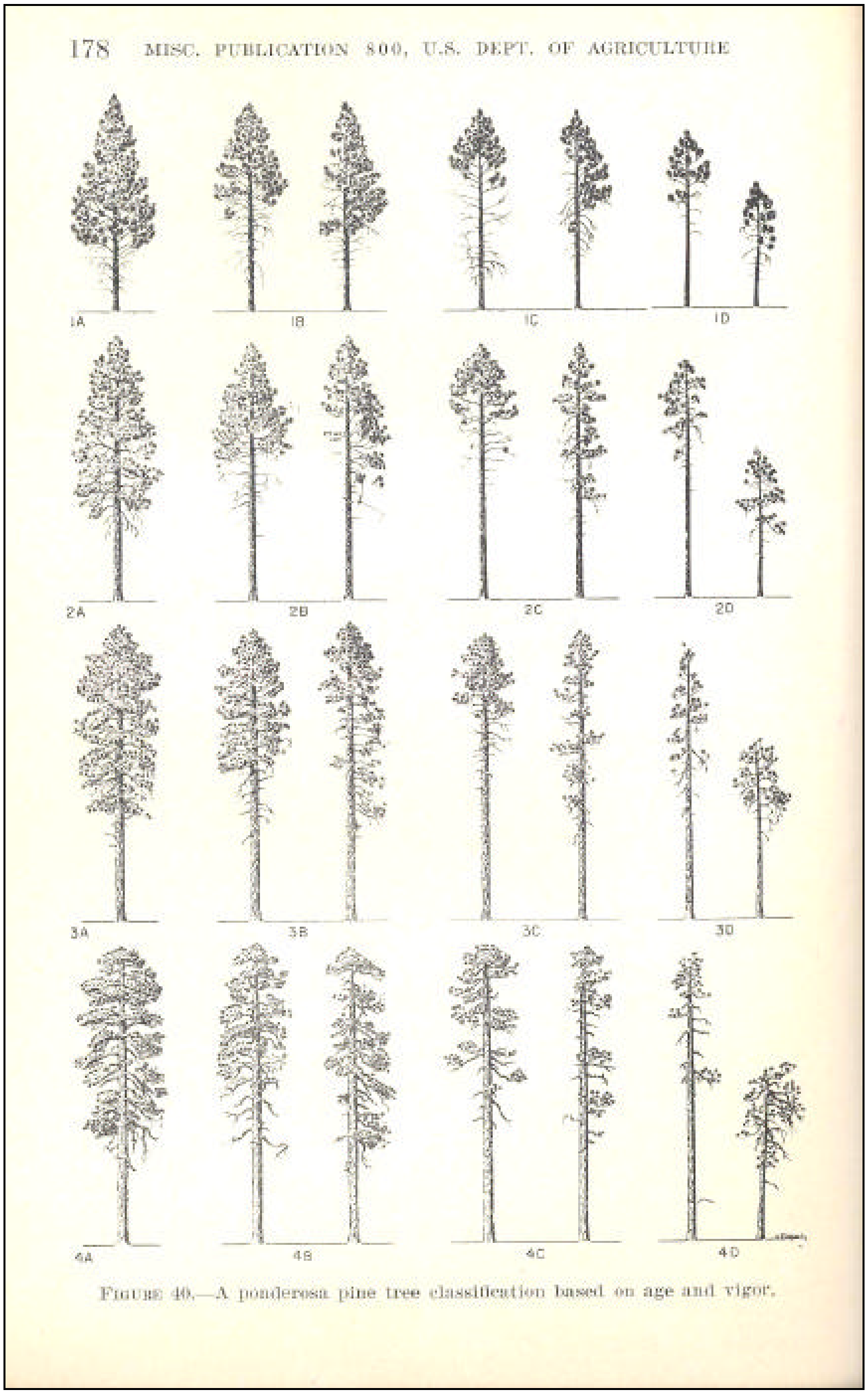
Class C: Fair to poor crowns, very narrow and sparse or represented by only a tuft of foliage at the top; foliage usually short and thin; position usually intermediate, sometimes codominant, rarely isolated; diameters below average for age

Class D: Crowns of very poor vigor; foliage sparse and scattered or only partially developed; position suppressed or intermediate; diameters decidedly subnormal, considering age

The combination of the two axes results in a total of 16 possible categories of crowns and tree sizes that are depicted in Figure A-1.

Keen (1936) found that the most important variable in predicting tree mortality was the condition of the crown, more so than tree age. The trees with “C” and “D” crowns were found to be susceptible to bark beetles, “B” crowns were of intermediate susceptibility, and trees with “A” crowns were generally resistant to bark beetle attack. Within the two groups of crowns associated with trees of poor vigor, the bark beetles appeared to prefer the “C” crowns and were less likely to infest trees with “D” crowns, possibly because they recognized these trees as poor-quality hosts (Keen 1936).

Figure A-1. F. P. Keen's classification of crowns of ponderosa pine based on tree age and vigor. Classes 1A, 1B, 2A, 3A, and 4A are considered resistant to attack by bark beetles; C and D classes in all ages are considered susceptible, and Classes 2B, 3B and 4B are of intermediate susceptibility (Keen 1936; Miller and Keen 1960).



Appendix B

Average diameters for ponderosa pine (measured at breast height (4.5 feet above ground) and western juniper (measured at root collar and aggregated into one measurement in the case of multiple stems trees) Lost Forest RNA, April/May 2005.

Ponderosa pine

Veg. type	Tran.	Average	Std. Deviation	Min	Max	N
Low sage	9	15.31	5.73	1.3	24.2	59
Big sage/Low sage	2	27.17	8.31	19.5	36	3
	3	16.44	10.17	0.8	31.6	16
	4	27.68	7.09	21.3	37.8	4
	11	23.54	13.84	6.1	41	5
Big sage	1	17.69	10.95	1.3	38.7	23
	5	21.24	15.81	0.1	35.8	5
	6	12.14	10.85	0.1	31.8	15
	7	21.78	13.6	1.5	30.1	4
Big sage/Bitter brush	8	11.76	11.54	0.5	40.2	44
	10	15.57	8.18	0.1	30.1	79
	12	14.35	8.05	0.5	33.4	66
	13	8.11	6.65	0.5	33.1	111

Western juniper

Veg Type	Tran.	Average	Std. Deviation	Min	Max	N
Low sage	9	11.33	8.28	0.2	42	188
Big sage/Low sage	2	15.51	9.44	2	48	87
	3	16.93	9.07	3	36	59
	4	16.28	8.76	3	42	40
	11	22.61	13.81	1	65	139
Big sage	1	29.17	15.37	0.1	88	53
	5	14.29	9.3	0.1	40	63
	6	19.34	11.44	0.1	58	146
	7	20.16	12.37	2	48	32
Big sage/Bitter brush	8	10.69	8.17	0.1	45	105
	10	9.25	6.36	2	34	72
	12	11.52	9.72	0.1	65	165
	13	8	7.3	0.2	40	125

Number of single stem juniper vs. multiple stem juniper.

Veg type	Tran	Single stem	Multiple stem
Low sage	9	31	16
Big sage/Low sage	2	10.25	11.5
	3	12.5	2.25
	4	4	5.75
	11	25	9.75
Big sage	1	7	6.25
	5	11.5	4.25
	6	29.75	6.75
	7	6.5	1.5
Big sage/Bitter brush	8	19.75	6.25
	10	13.25	4.75
	12	36.25	4.75
	13	27.5	3.75

Appendix C

Radial growth rates (expressed in “20ths of an inch”) from the last ten years for 25 western junipers and 36 ponderosa pines cored on 1/10th-acre plots along survey transects, Lost Forest RNA, April/May 2005.

Western juniper

Veg. Type	Tran.	N	Avg.	Min	Max
Low sage	9	3	3.33	3	4
Big sage/Low sage	2	1	5		
	3	2	5.5	4	7
	4	1	11		
	11	2	8.5	8	9
Big sage	1	1	3		
	5	2	15.5	12	19
	6	5	5.8	4	8
	7				
Big sage/Bitter brush	8	1	5		
	10	2	9	7	11
	12	4	6	3	10
	13	1	6		

Ponderosa pine

Veg. Type	Tran.	N	Avg.	Min	Max
Low sage	9	6	5.17	2	7
Big sage/Low sage	2	0			
	3	3	15	3	27
	4	0			
	11	3	22.33	6	39
Big sage	1	1	10		
	5	1	23		
	6	2	10.5	5	16
	7	0			
Big sage/Bitter brush	8	3	16.67	9	28
	10	8	5.88	2	11
	12	8	13.5	6	22
	13	1	24		